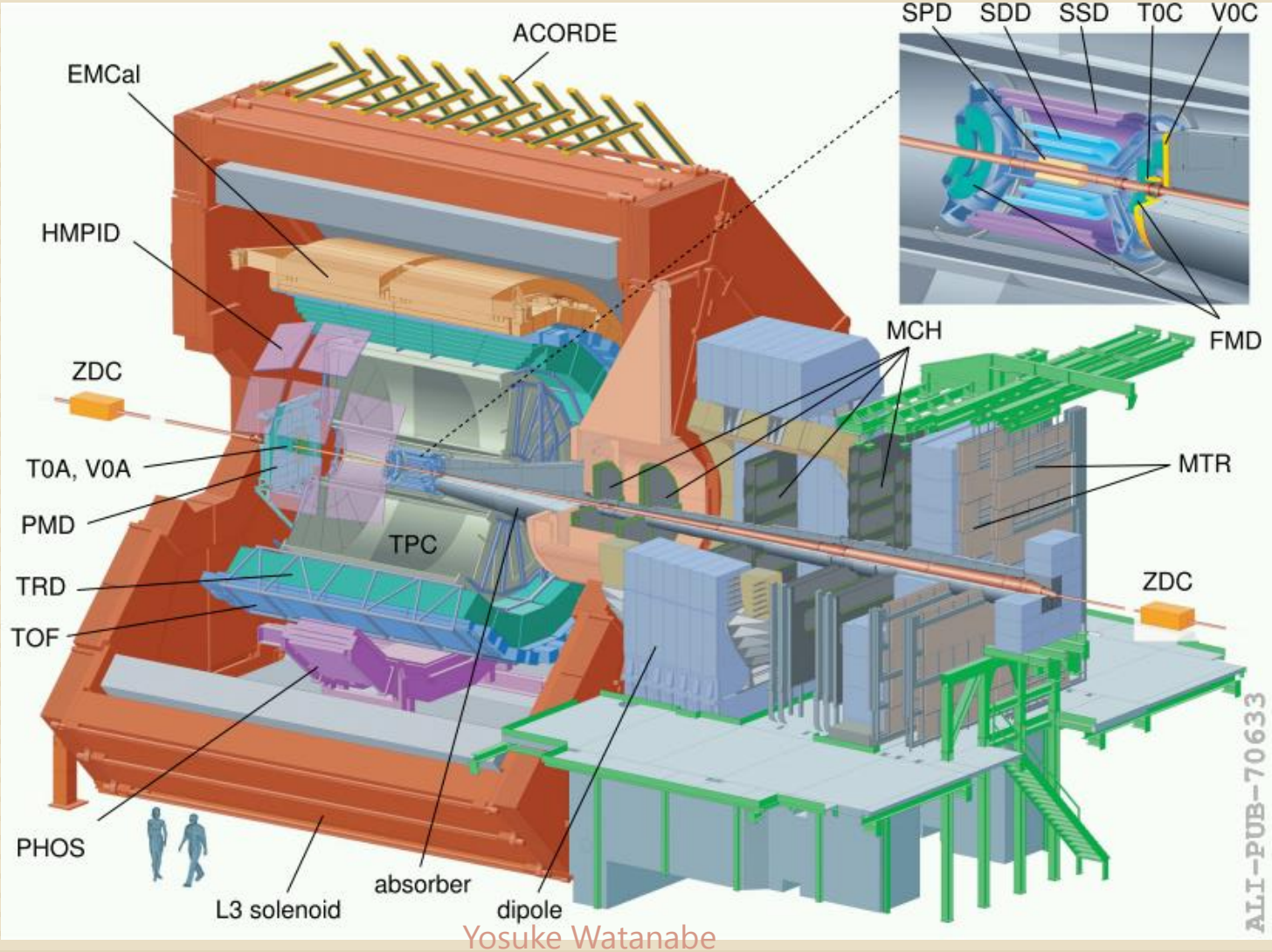
ALICE overview

Yosuke Watanabe for the ALICE collaboration
CNS, the University of Tokyo

ALICE detector



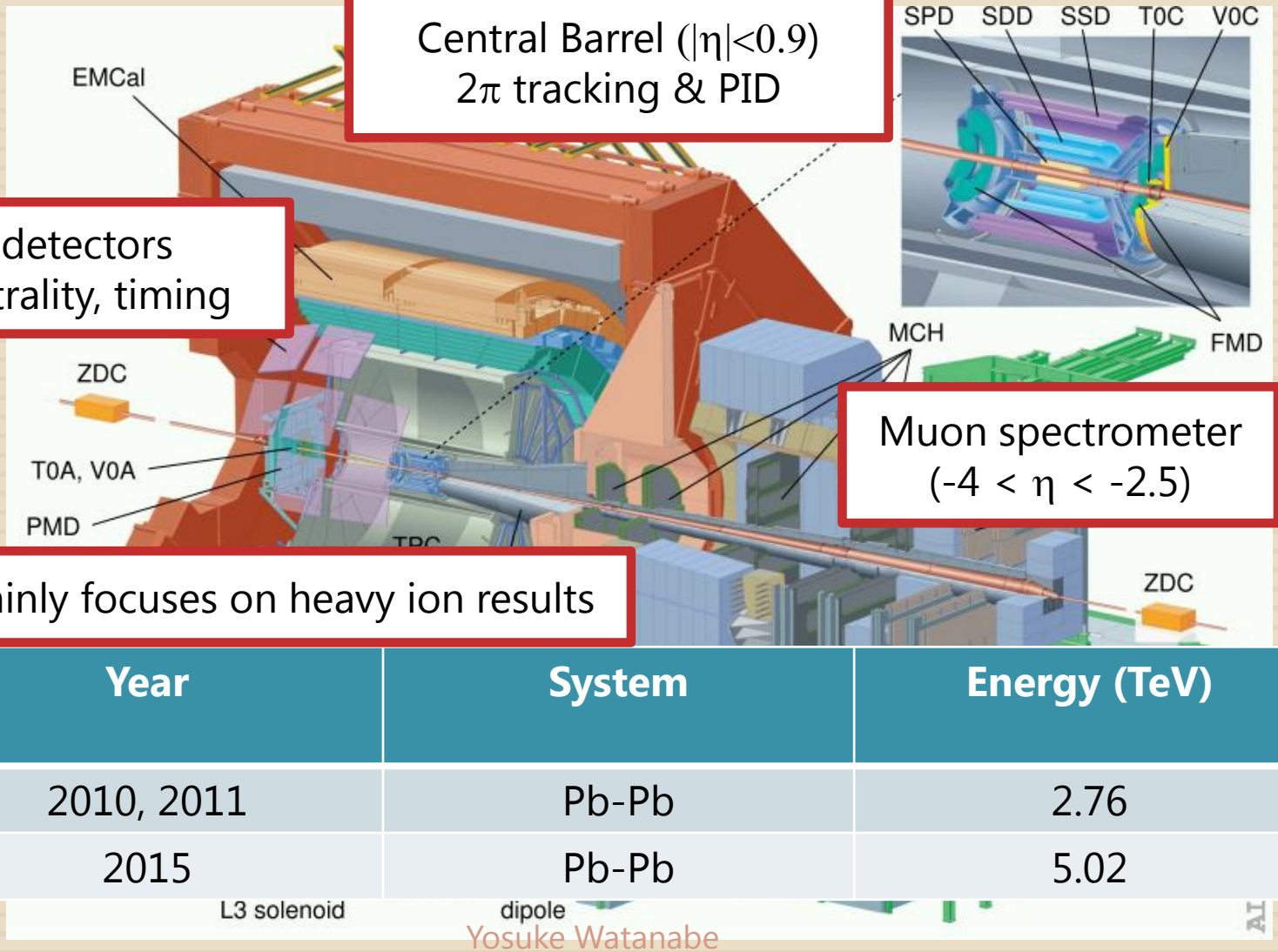
ALICE detector

Central Barrel ($|\eta|<0.9$)
2π tracking & PID

Forward detectors
Trigger, centrality, timing

Muon spectrometer
($-4 < \eta < -2.5$)

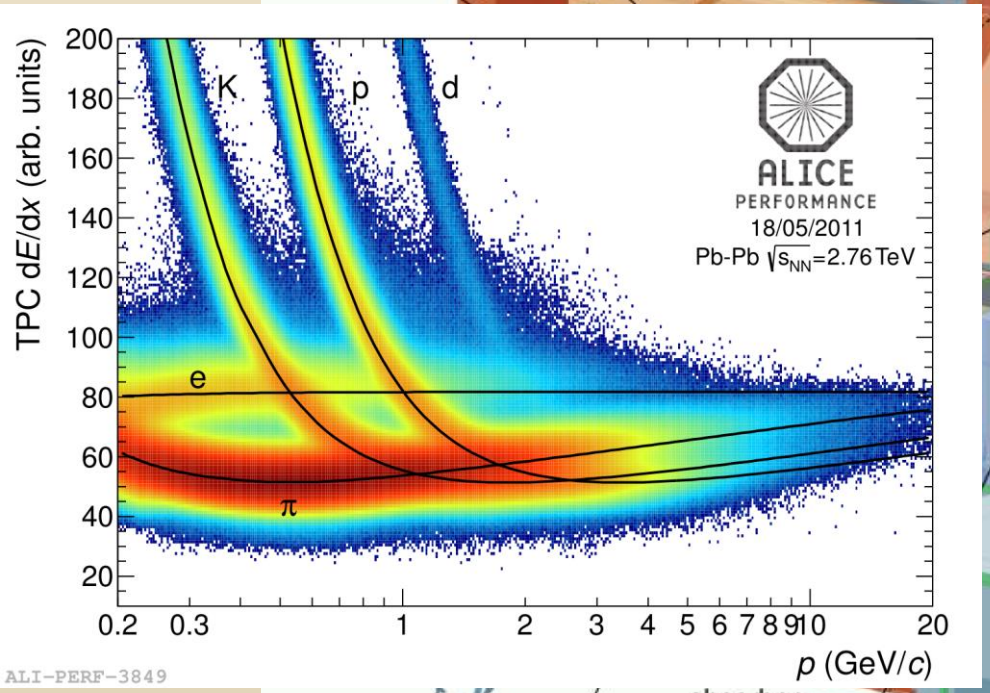
This talk mainly focuses on heavy ion results

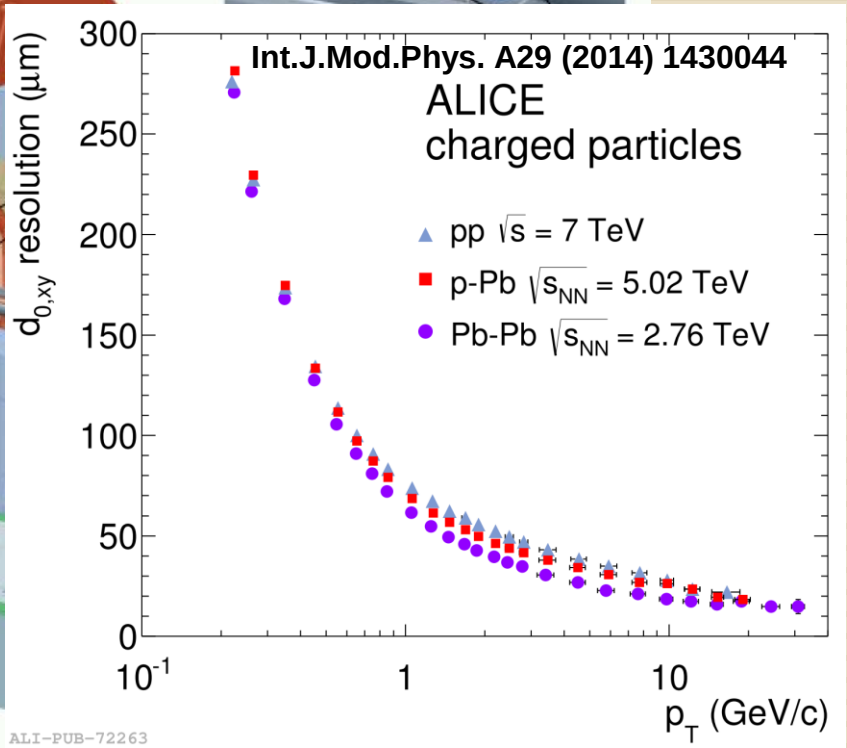


Year	System	Energy (TeV)
2010, 2011	Pb-Pb	2.76
2015	Pb-Pb	5.02

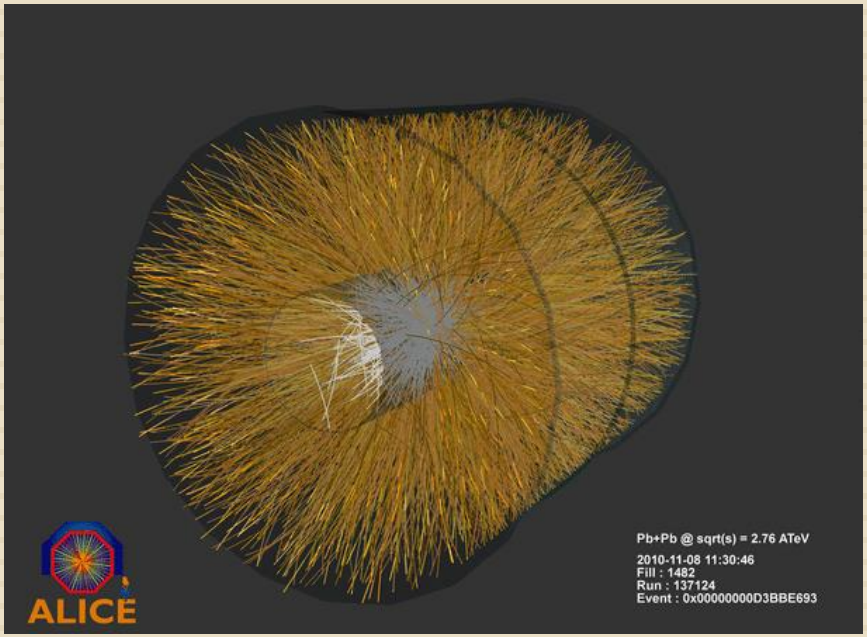
ALICE detector

- Excellent PID (hadrons, leptons, photons) and jets
- Excellent vertex capability (HF, V^0s, cascades, conversions)
- Efficient low-momentum tracking down to 150 MeV/c





Experimental probes of QGP



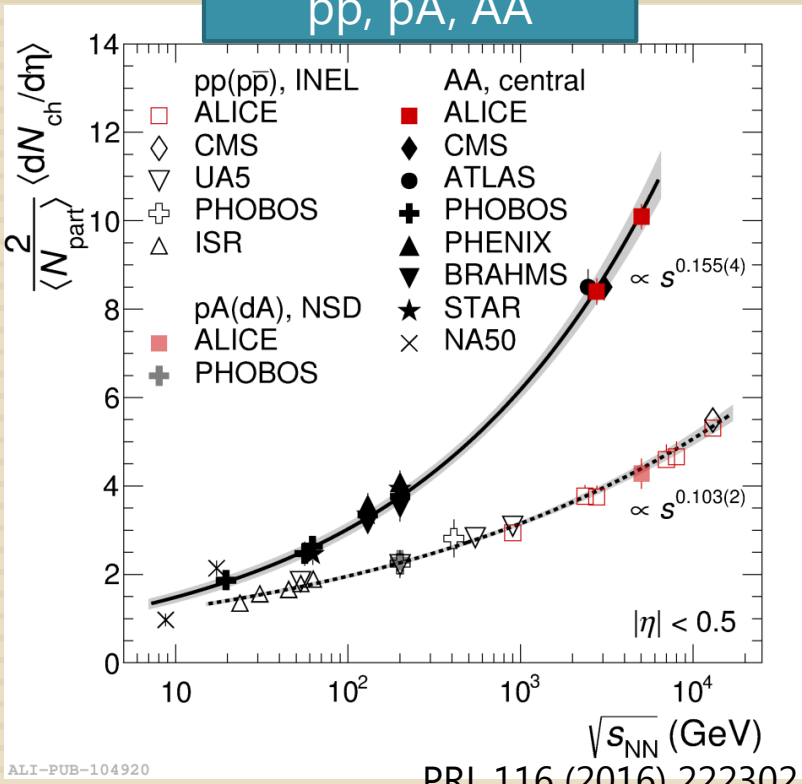
Discussed in this talk

- Global observables
- Flow
- Jet suppression
- Heavy flavor
- Quarkonia
- Light flavor resonances
- EM probes

- Only selected results from these topics are discussed
- You can find much more at:
  - http://aliceinfo.cern.ch/ArtSubmission/submitted

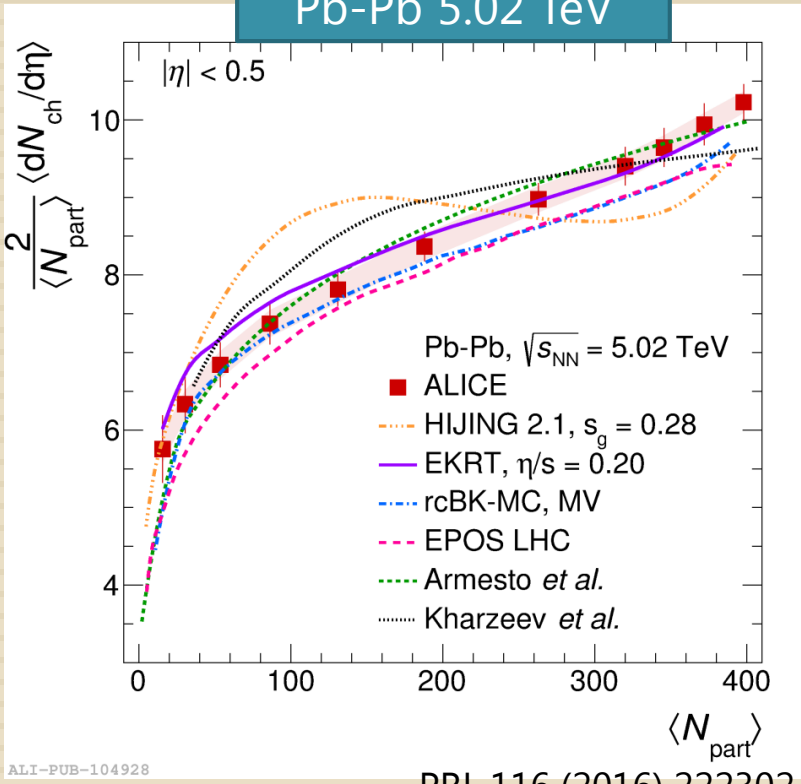
Multiplicity

pp, pA, AA



PRL 116 (2016) 222302

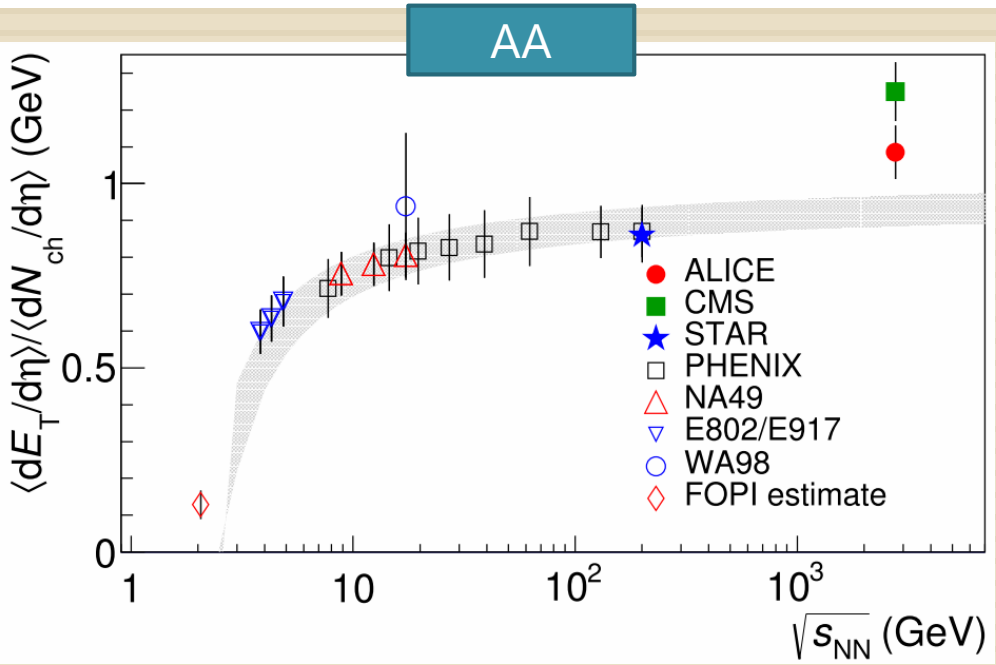
Pb-Pb 5.02 TeV



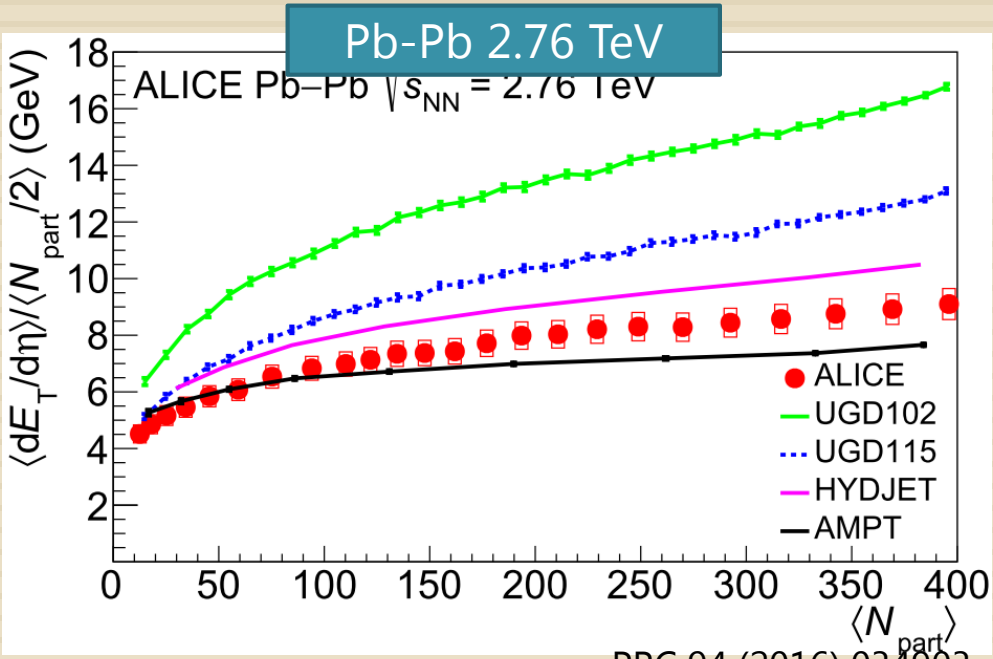
PRL 116 (2016) 222302

- Pb-Pb at 5.02 TeV: highest energy so far
  - For 0-5% most central collisions, confirms trend from lower energies
- $\langle dN_{ch}/d\eta \rangle$ vs $\langle N_{part} \rangle$: Provide further constraints for models

Transverse energy



PRC 94 (2016) 034903

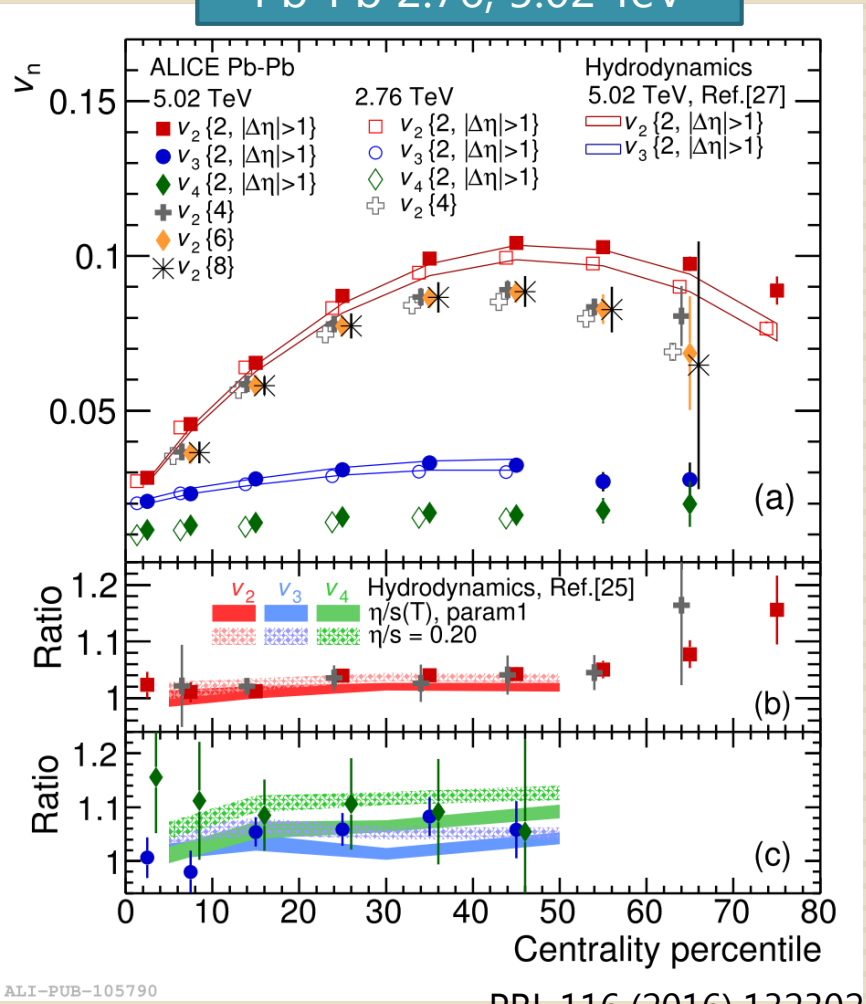


PRC 94 (2016) 034903

- At LHC energies, the increase in collision energy increases not only multiplicity but also the mean energy per particles
- None of the available models is able to describe the data very well
- $\varepsilon\tau_0$ = 12.3±1.0 GeV/fm^2/c (0-5%)
  - x 2.3 of 0-5% Au-Au collisions measured at RHIC

Anisotropic flow

Pb-Pb 2.76, 5.02 TeV

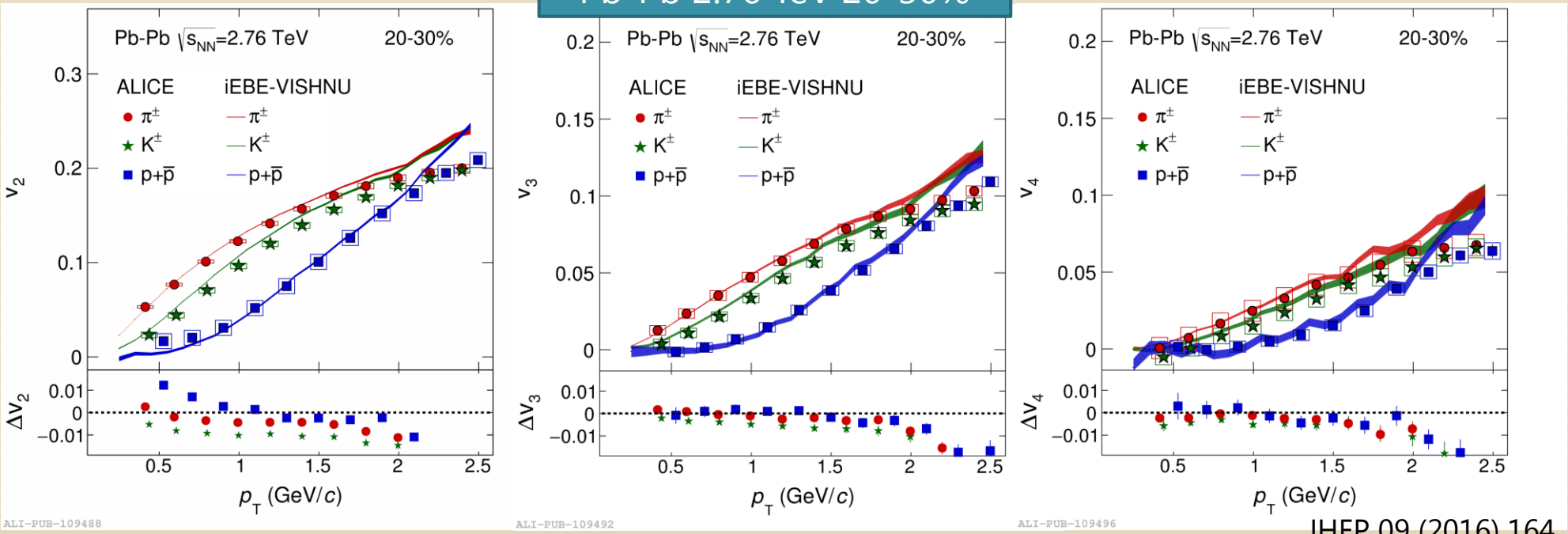


PRL 116 (2016) 132302

- p_T integrated (0.2-5 GeV/c) v_2, v_3, v_4 measurements
  - two- and multi-particle cumulants
  - $v_n\{2\}$: Nonflow effects are suppressed by the requirement $|\Delta\eta| > 1$
- v_n (5.02 TeV) > v_n (2.76 TeV)
  - Attributed to the increase in $\langle p_T \rangle$
- $v_2\{2, |\Delta\eta|>1\} > v_2\{4,6,8\}$
  - Can be related to elliptic flow fluctuations
- Good agreement with hydrodynamical calculations
  - Measurements support a low value of the shear viscosity to entropy density ratio

Identified particle v_n

Pb-Pb 2.76 TeV 20-30%

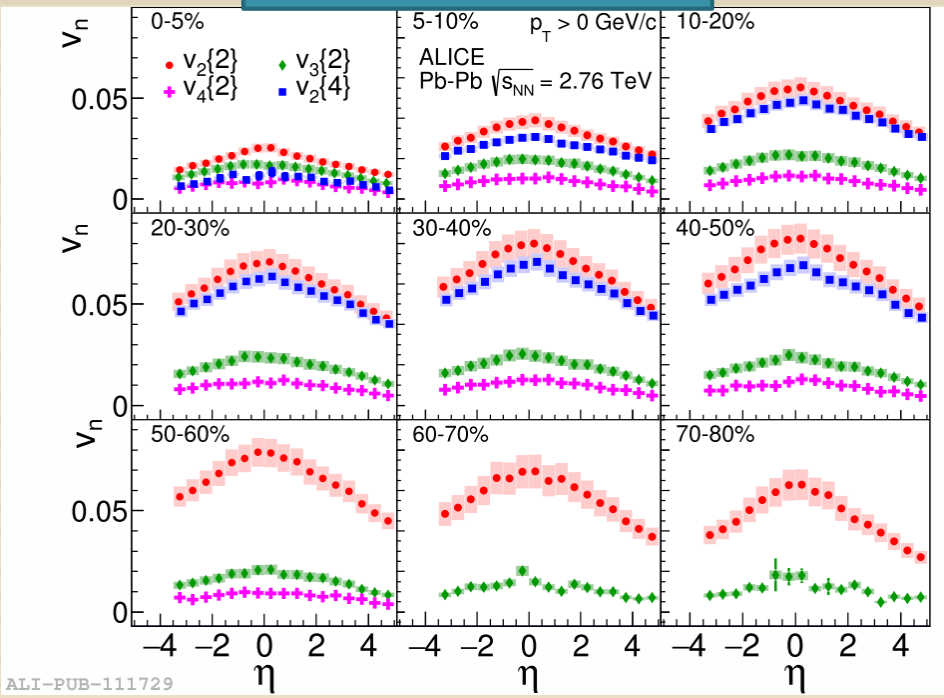


JHEP 09 (2016) 164

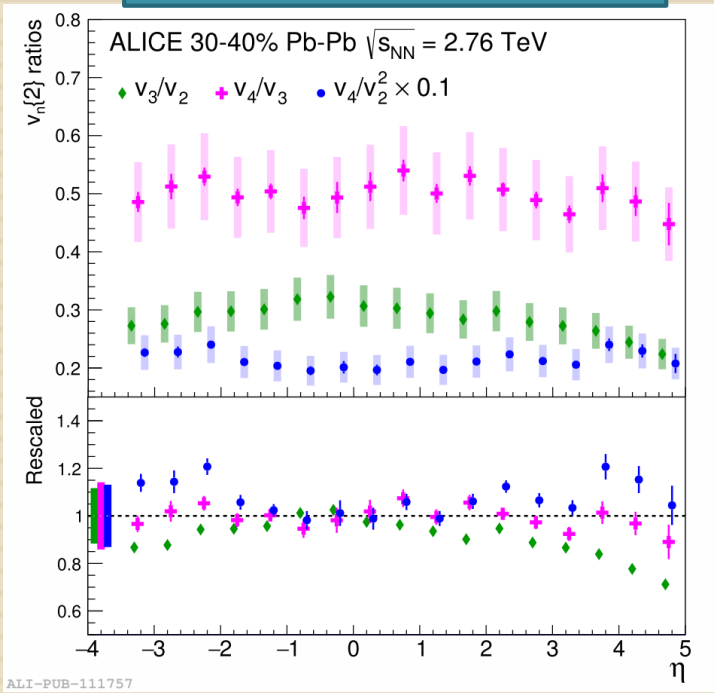
- Mass ordering of v_n at p_T < ~2 GeV/c for n = 2, 3, 4
- The mass ordering is qualitatively well described by a hydrodynamical model (iEBE-VISHNU) with η/s = 0.08 (conjectured lower limit)
  - ~10% deviations between data and the model still remaining

η dependence

Pb-Pb 2.76 TeV



Pb-Pb 2.76 TeV 30-40%

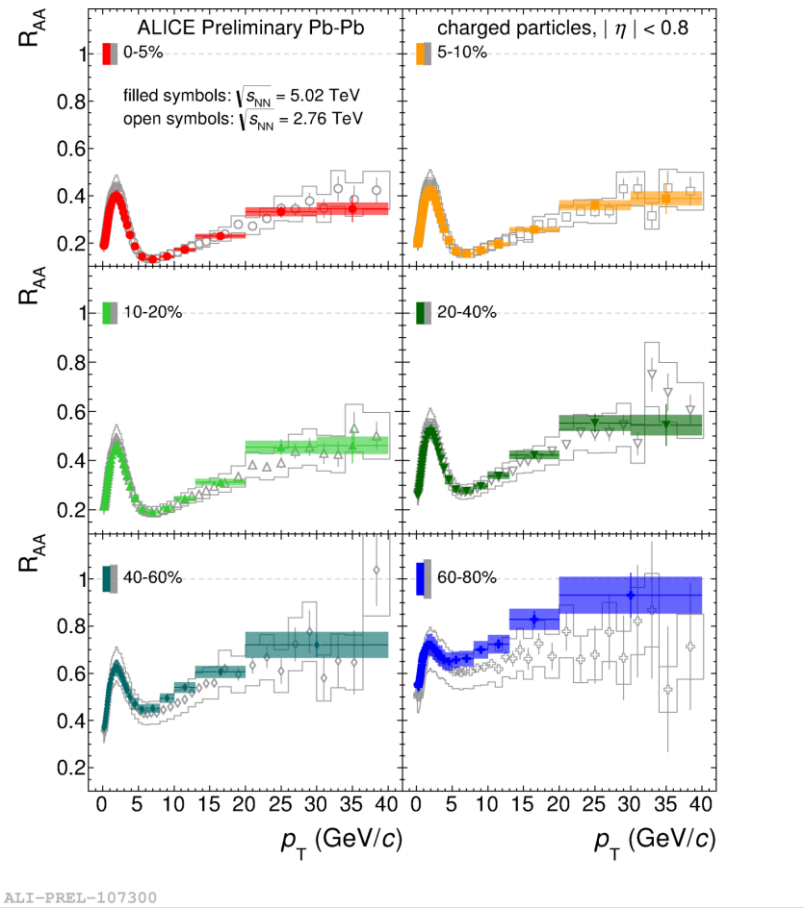


PLB 762 (2016) 376

- Potentially constrain the temperature dependence of η/s
  - E. Molnar et al (PRC 90 (2014) 044904), G. Denicol et al (PRL 116 (2015) 212301)
- No clear centrality dependence in the shape of $v_n(\eta)$
- v_3/v_2 decreases as going towards the forward rapidity
  - Low T at forward rapidity → Greater role of hadronic viscosity → Higher order v_n suppressed (?)

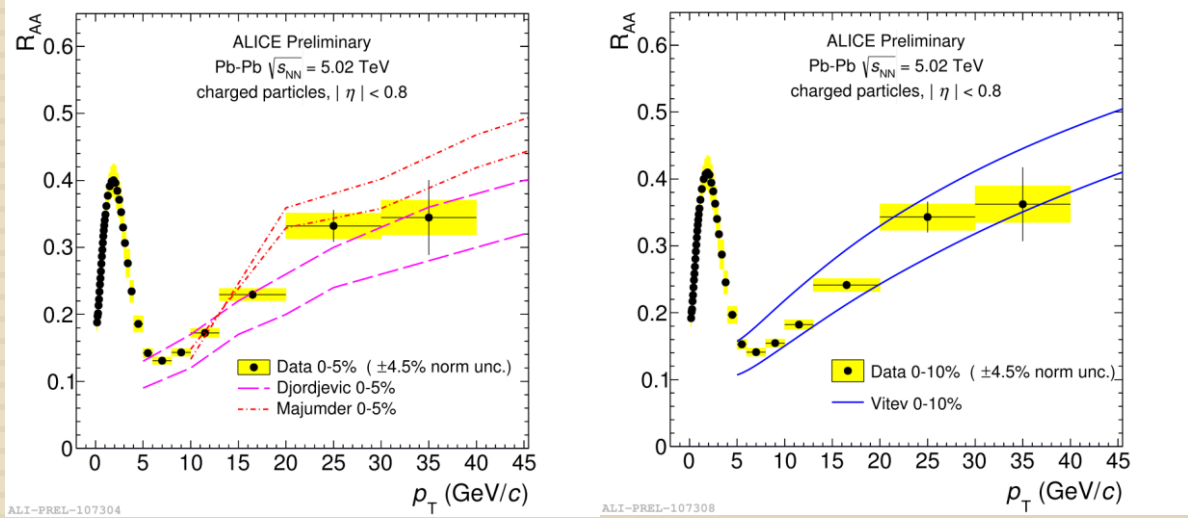
Single particle R_{AA}

Pb-Pb 2.76, 5.02 TeV



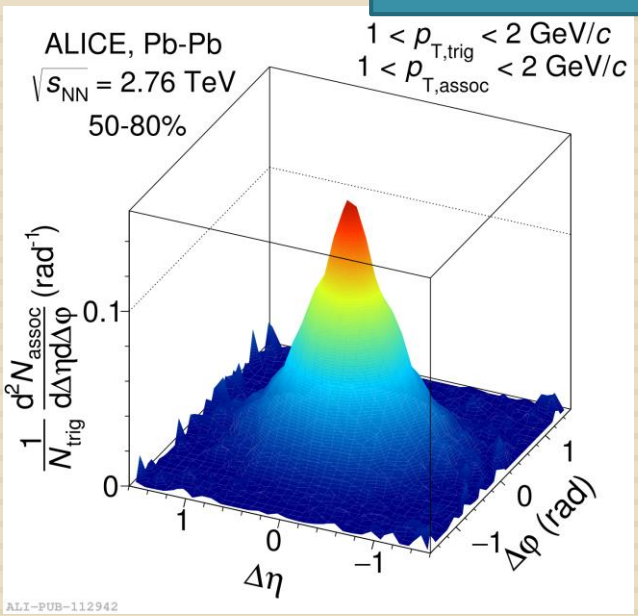
- Stronger suppression in more central bins
- R_{AA} at 5.02 TeV ~ R_{AA} at 2.76 TeV
  - Harder p_T spectrum
  - Increased parton energy loss
- Model predictions are in agreement with the measurement

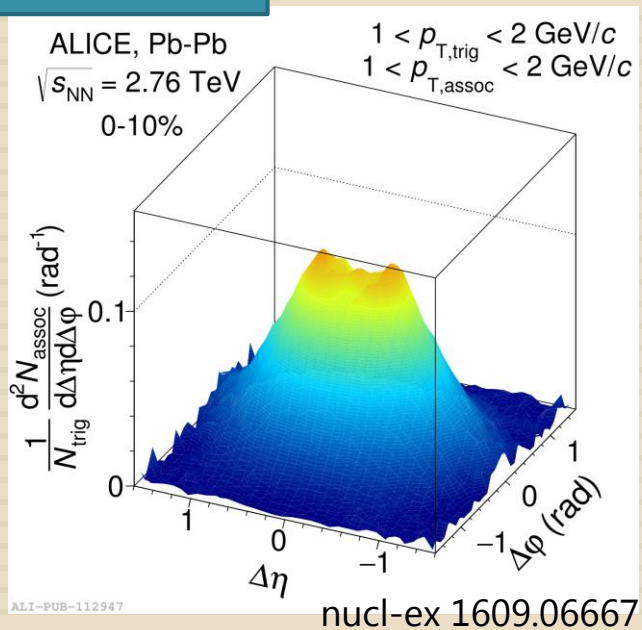
Pb-Pb 5.02 TeV



Two-particle correlation

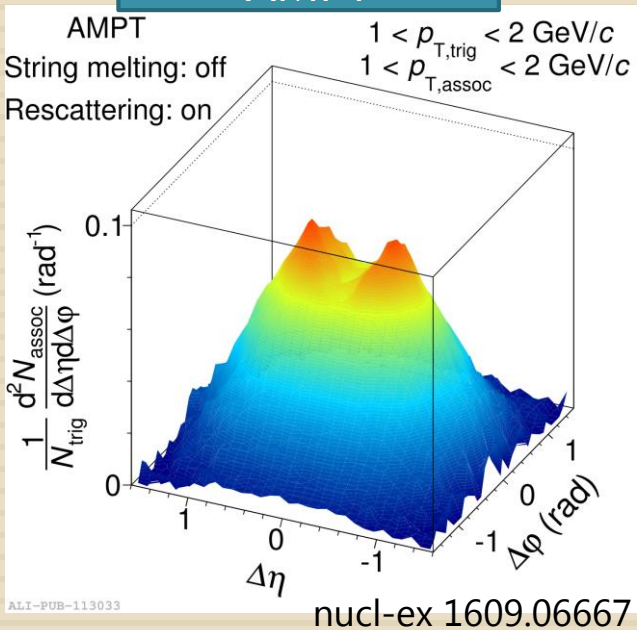
Pb-Pb 2.76 TeV





nucl-ex 1609.06667

AMPT

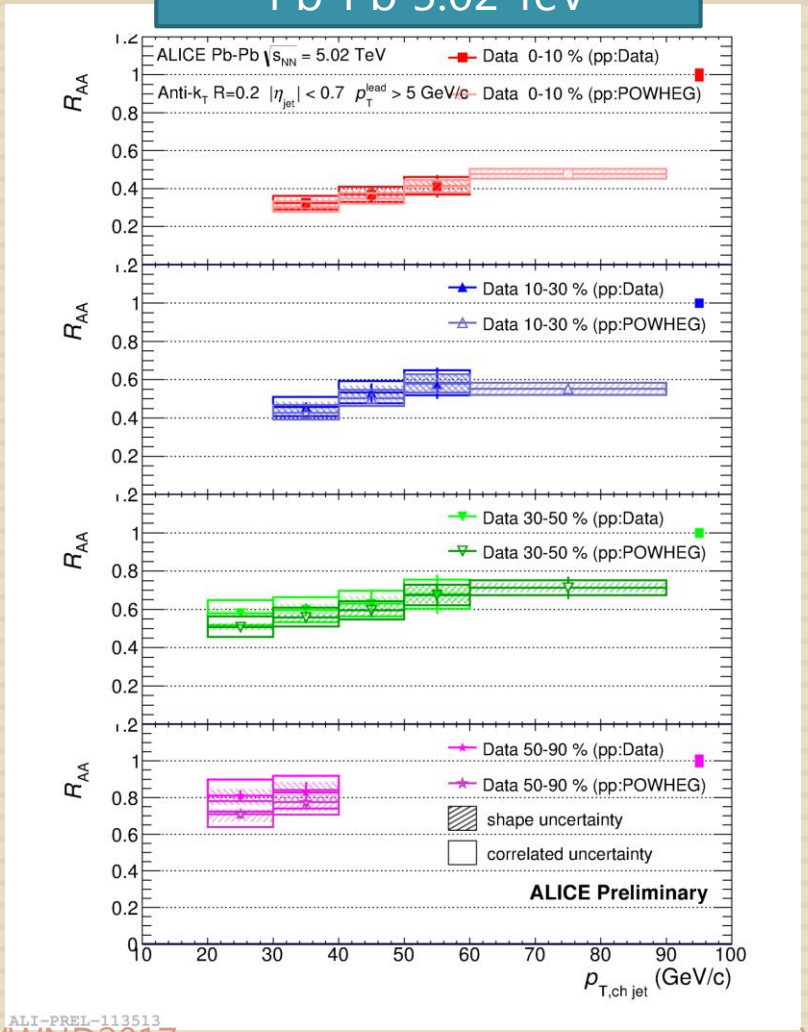


nucl-ex 1609.06667

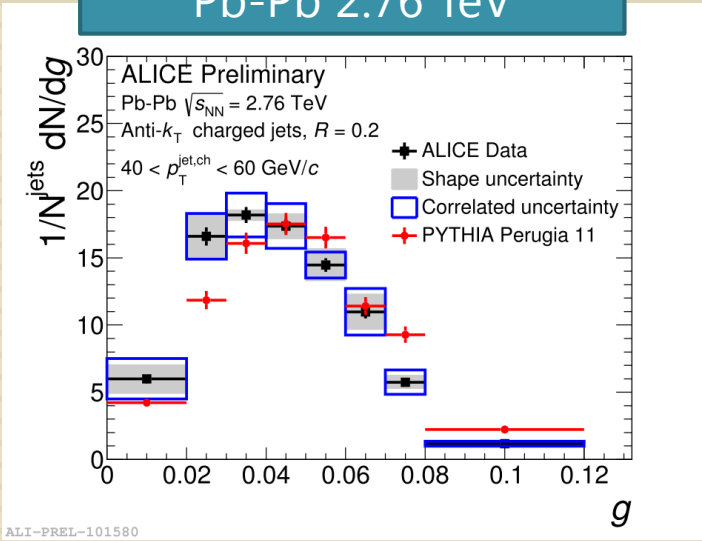
- Moderate broadening in $\Delta\phi$, large broadening in $\Delta\eta$, depletion at the center of the peak
- AMPT (melting: OFF, rescattering: ON)
  - Describes both peak broadening and depletion in data: importance of the hadronic phase
  - The modifications are caused by the interplay between jets and the collective motion of the medium, such as radial flow

Charged-particle jet

Pb-Pb 5.02 TeV



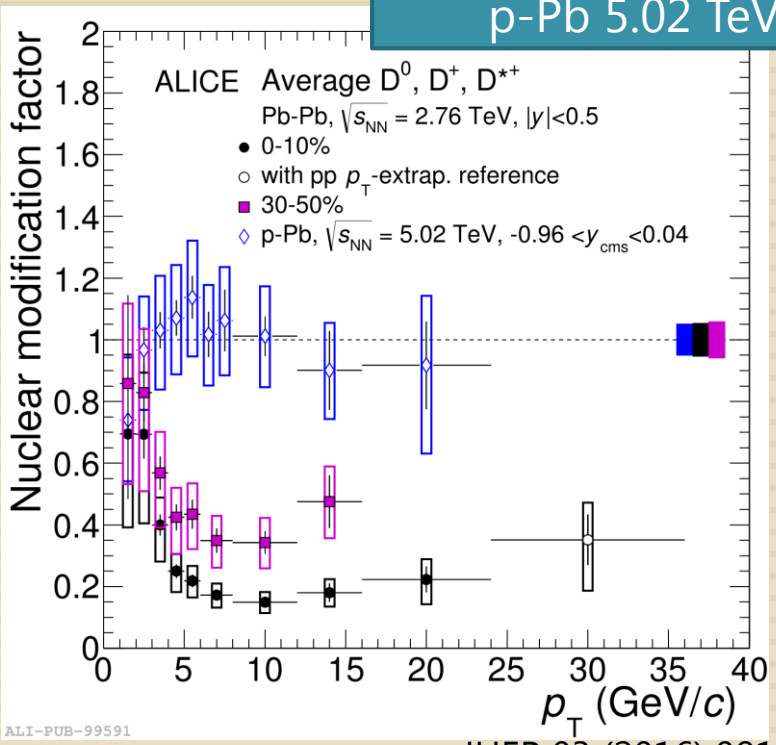
Pb-Pb 2.76 TeV

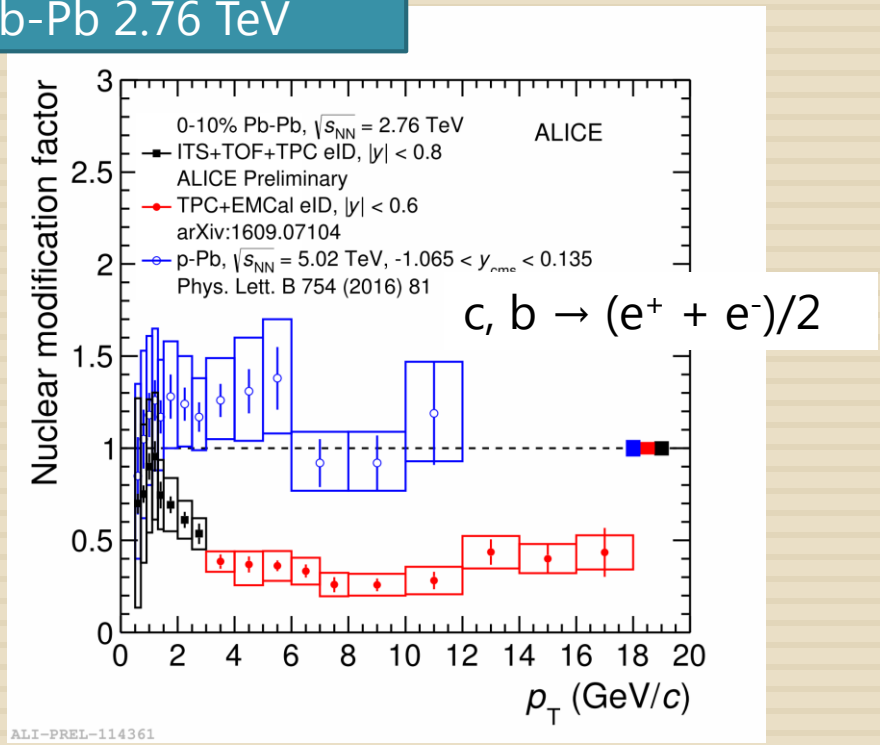


- Get closer access to parton energy
- R_{AA} : stronger suppression in central than in peripheral collisions
- Enables the studies of jet structures
  - Radial moment (g): p_T weighted jet width
    - Shifted to lower values in Pb-Pb compared to PYTHIA: indication of more collimated jet cores

Heavy flavor at midrapidity

p-Pb 5.02 TeV, Pb-Pb 2.76 TeV



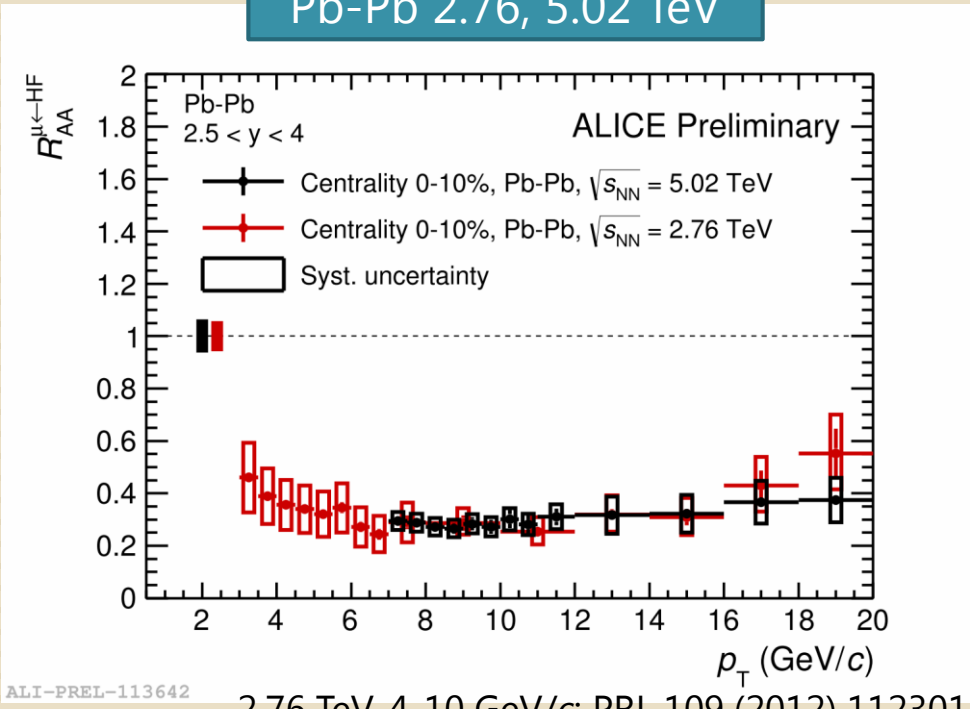


JHEP 03 (2016) 081

- Heavy flavor production is studied using hadronic decays and electron decays of heavy-flavor hadrons
- Strong suppression at high p_T in Pb-Pb collisions
  - Not seen in p-Pb collisions: strong suppression is final state effects
  - Stronger in central than in semi-central collisions: in-medium energy loss of charm quarks

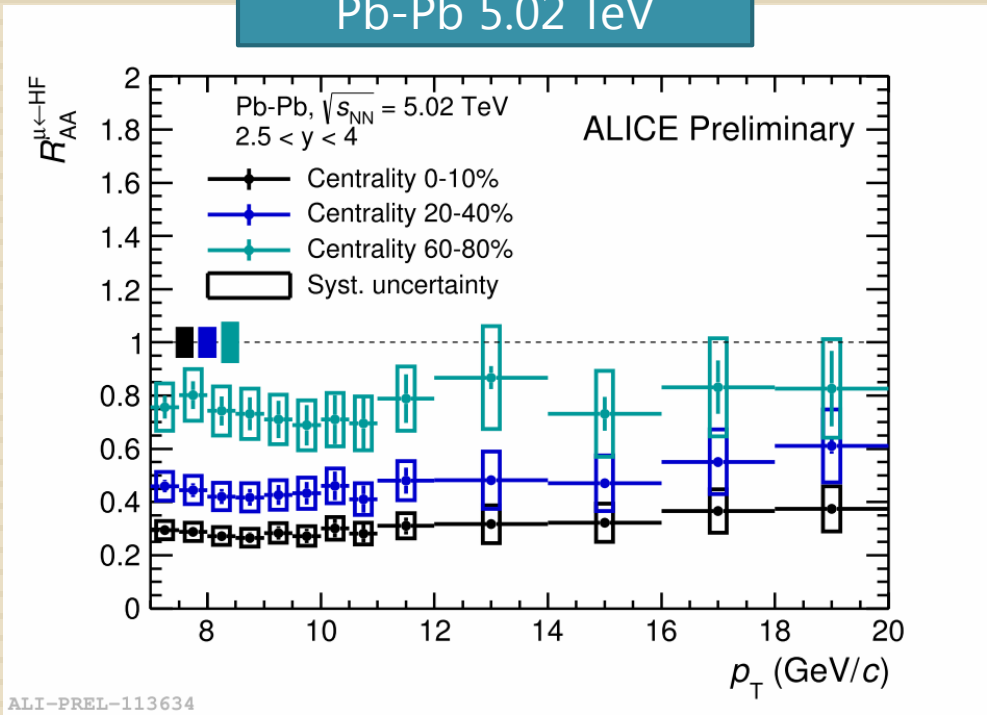
Heavy flavor at forward rapidity

Pb-Pb 2.76, 5.02 TeV



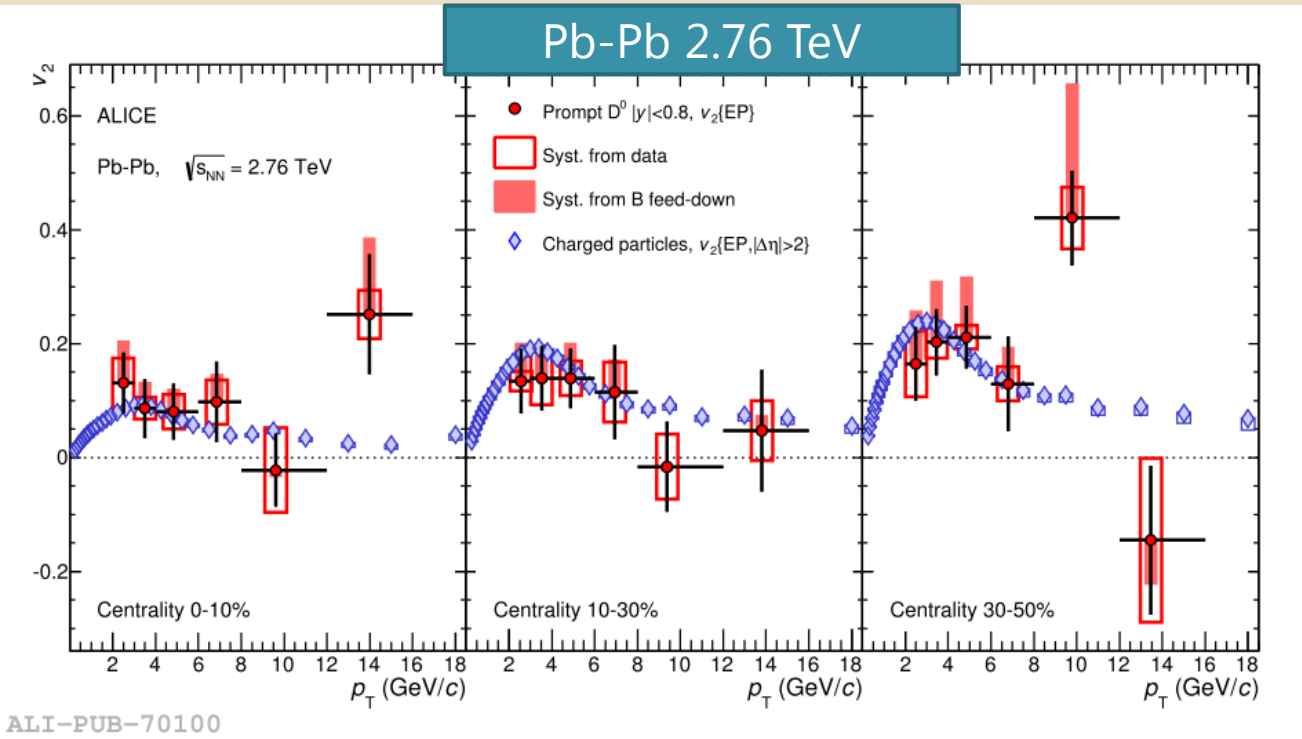
2.76 TeV, 4-10 GeV/c: PRL 109 (2012) 112301

Pb-Pb 5.02 TeV



- Heavy flavor production at forward rapidity is studied using the muon decays
- Heavy-flavor decay muons are suppressed in the most central collisions
  - Similar suppression at 5.02 TeV and 2.76 TeV
- Stronger suppression in central than in peripheral collisions similarly to the observation at midrapidity.

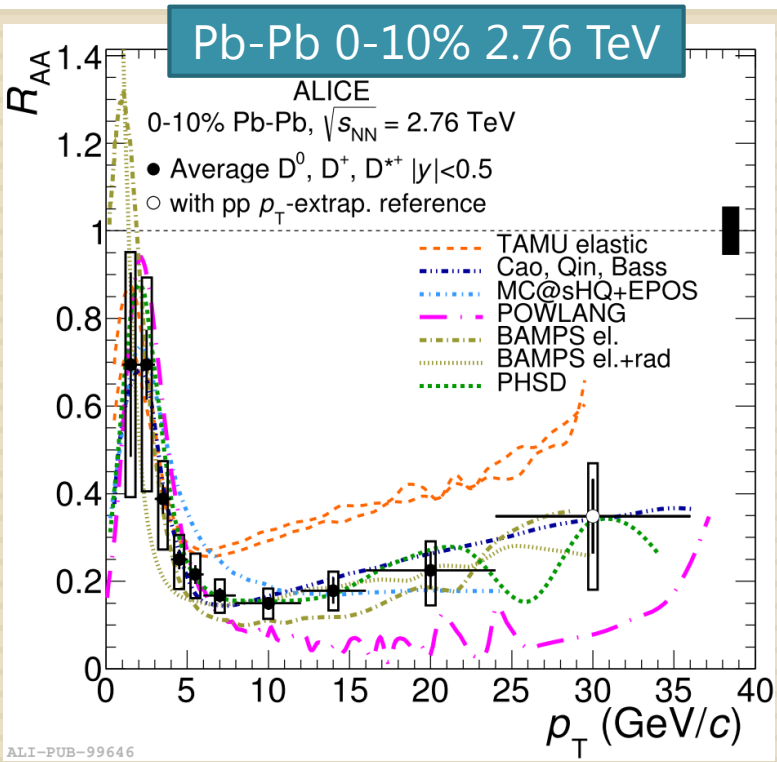
Elliptic flow

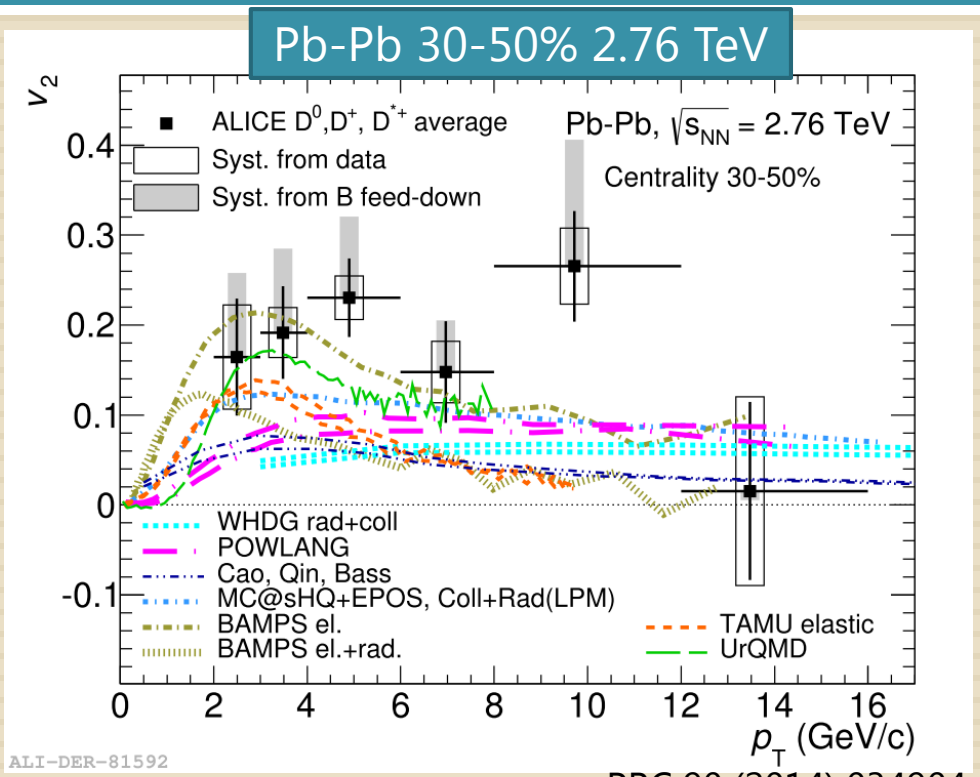


PRC 90 (2014) 034904

- Positive v_2 is observed (5σ effect for $2 < p_T < 6$ GeV/c in 30-50% centrality bin)
  - electron: JHEP 09 (2016) 028, muon: PLB 753 (2016) 41
- D-meson v_2 tends to be larger in semi-central than in central collisions
- D-meson v_2 is similar to that of charged particles
  - Significant interaction of charm quarks with the medium (PRL 111 (2013) 102301)

Comparison with models



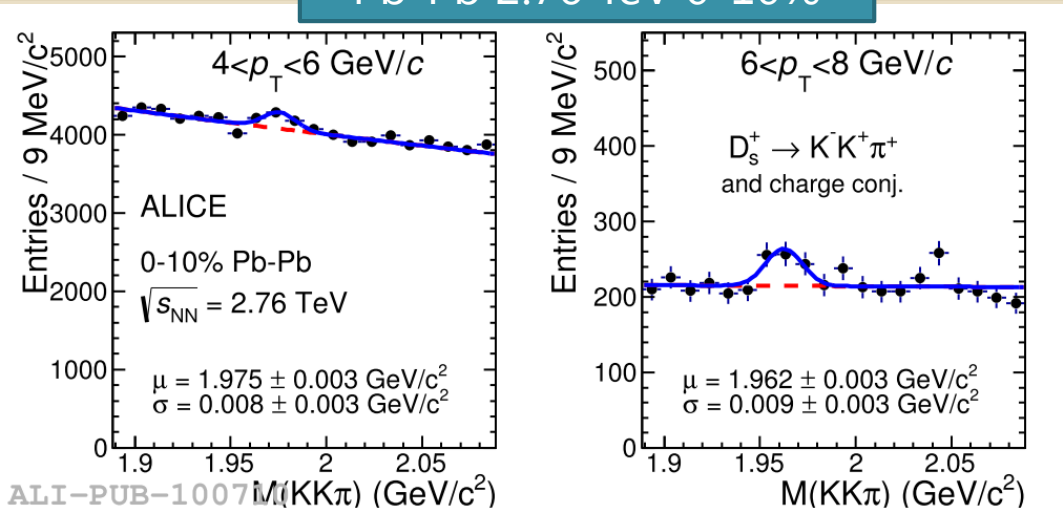


PRC 90 (2014) 034904

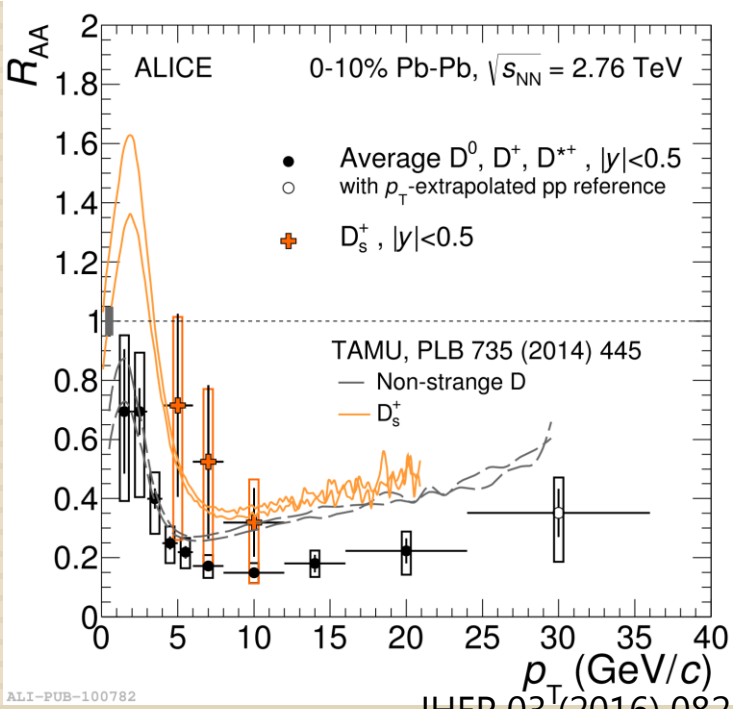
- Various models with different energy-loss mechanisms, fireball evolution, hadronization, etc
- Simultaneous description of R_{AA} and v_2 seems challenging for models
  - Similar observations for electrons and muons from heavy-flavor decays

D_s^+

Pb-Pb 2.76 TeV 0-10%



JHEP 03 (2016) 082

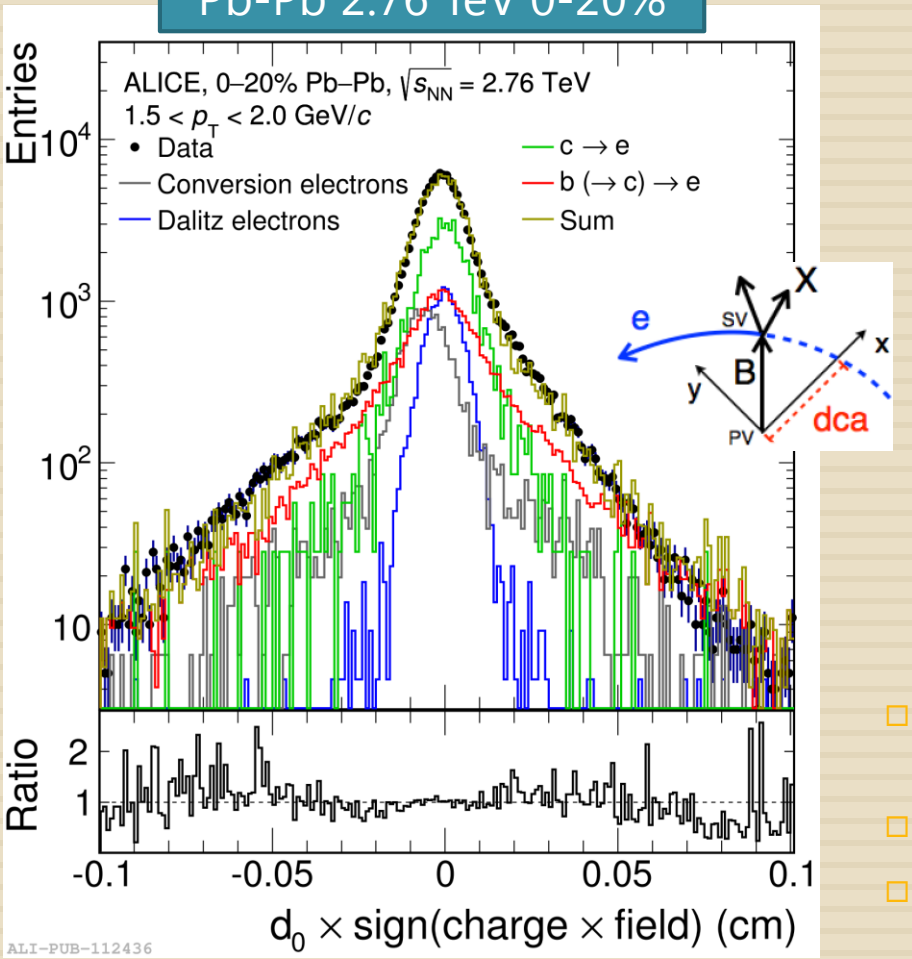


JHEP 03 (2016) 082

- D_s^+ provides a unique insight into charm-quark hadronization mechanism
  - Strangeness enhancement in heavy-ion collisions affects charm-quark hadronization in the coalescence picture
- p_T>8 GeV/c: compatible with other D mesons
- p_T<8 GeV/c: hint of less suppression

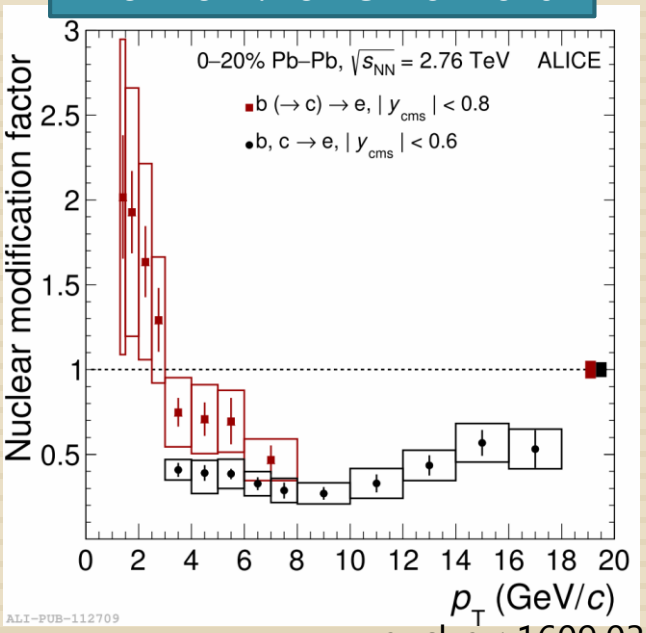
b (→ c) → e

Pb-Pb 2.76 TeV 0-20%



nucl-ex: 1609.03898

Pb-Pb 2.76 TeV 0-20%

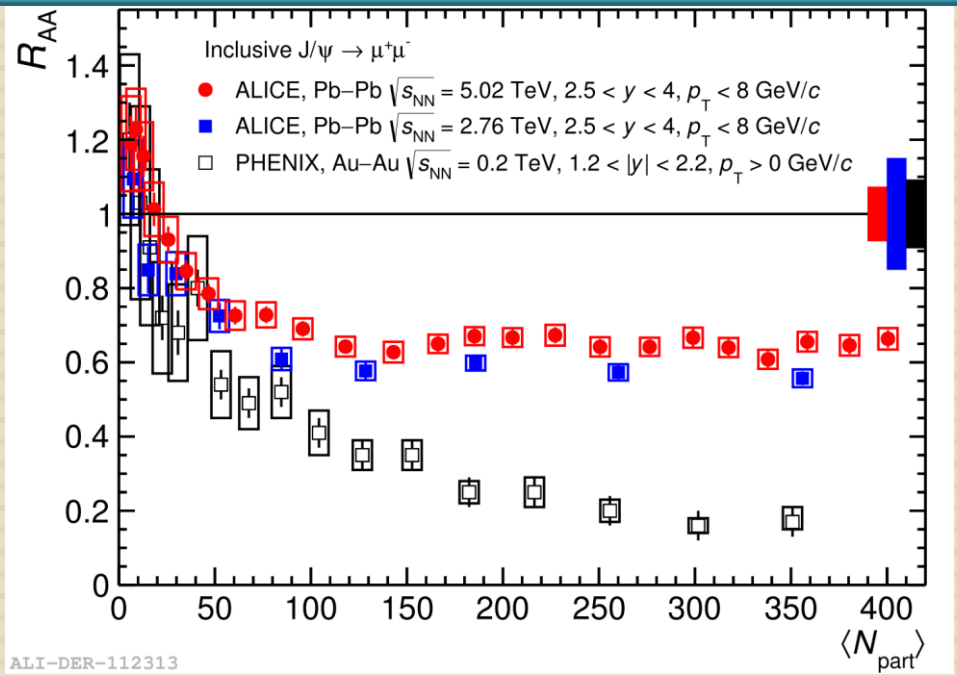


nucl-ex: 1609.03898

- Electrons from beauty quarks are identified with their large impact parameter
- Hint of R_{AA} < 1 for p_T > 3 GeV/c
- Consistent with the expected hierarchy in the energy loss
  - $\Delta E_c > \Delta E_b$

J/ψ suppression

Au-Au 200 GeV, Pb-Pb 2.76, 5.02 TeV (forward)



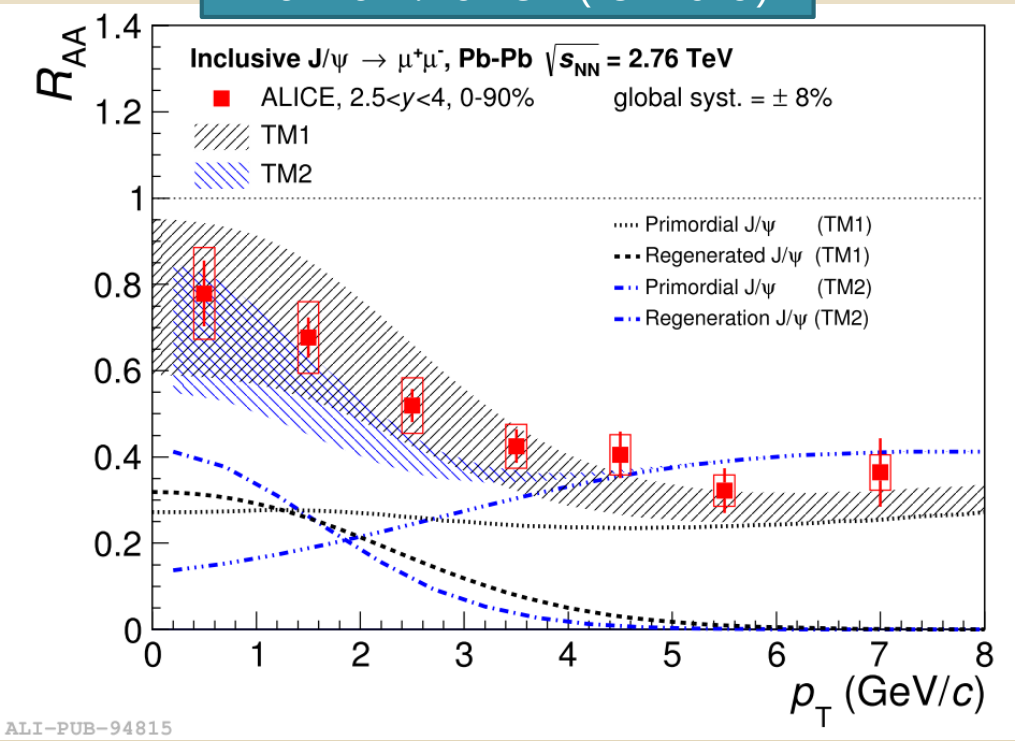
nucl-ex: 1606.08197

- Clear J/ψ suppression
  - Less suppression than at RHIC
  - Less suppression at 5.02 TeV than at 2.76 TeV
  - Almost no centrality dependence above N_{part} ~100

Significant role of regeneration

p_T dependence

Pb-Pb 2.76 TeV (forward)

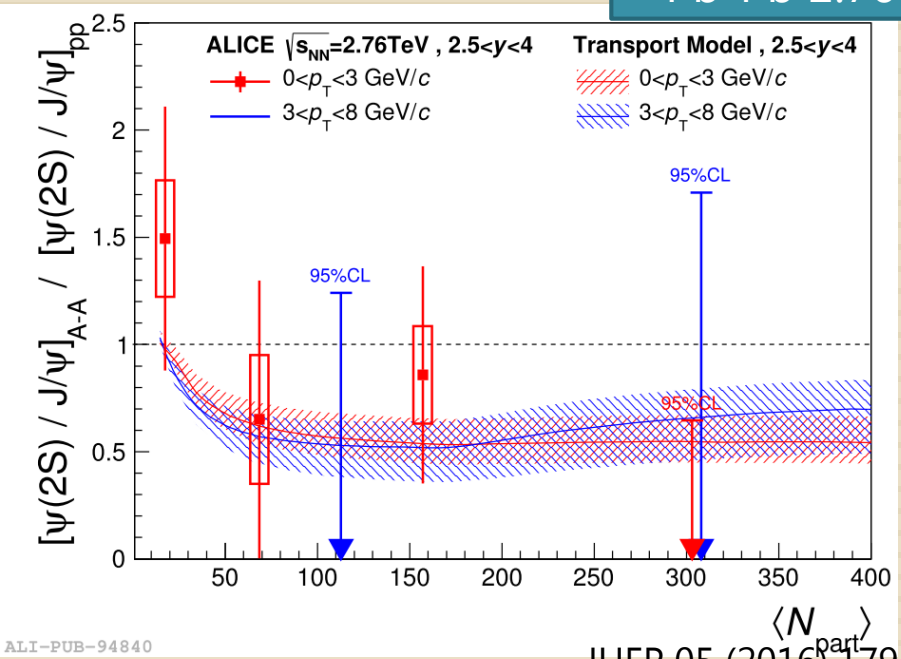


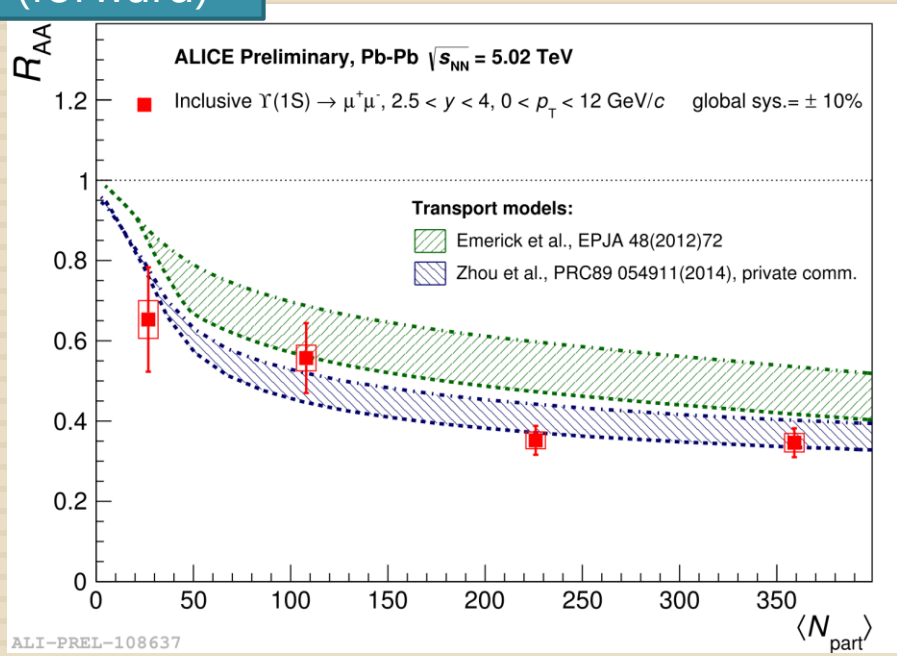
JHEP 05 (2016) 179

- Reasonably well described by transport model calculations
- Regenerated J/ψ contribution concentrated at low p_T

ψ(2S) and Υ(1S)

Pb-Pb 2.76 TeV (forward)



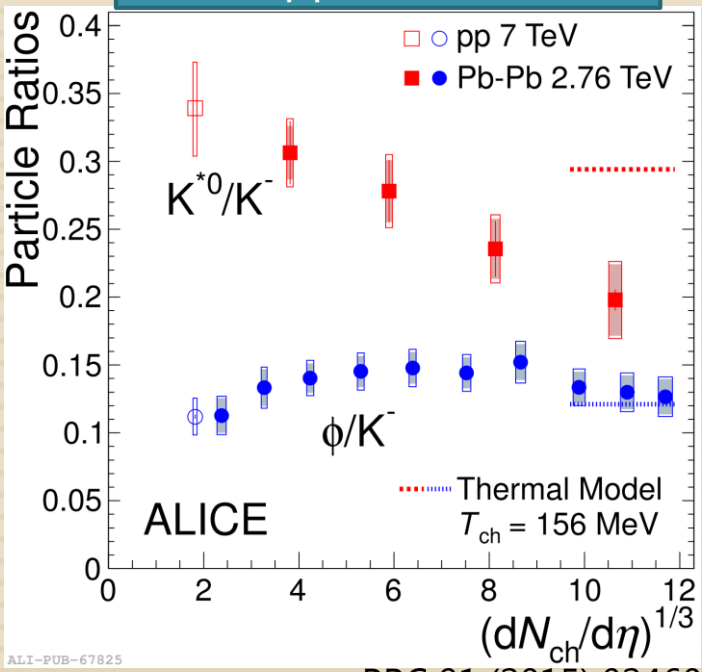


JHEP 05 (2016) 179

- ψ(2S)
  - Hint of larger suppression in central collisions
  - Data points are described by the transport model calculations within uncertainties
- Υ(1S)
  - Centrality dependence is qualitatively reproduced
  - Suppression is slightly underestimated when considering regeneration

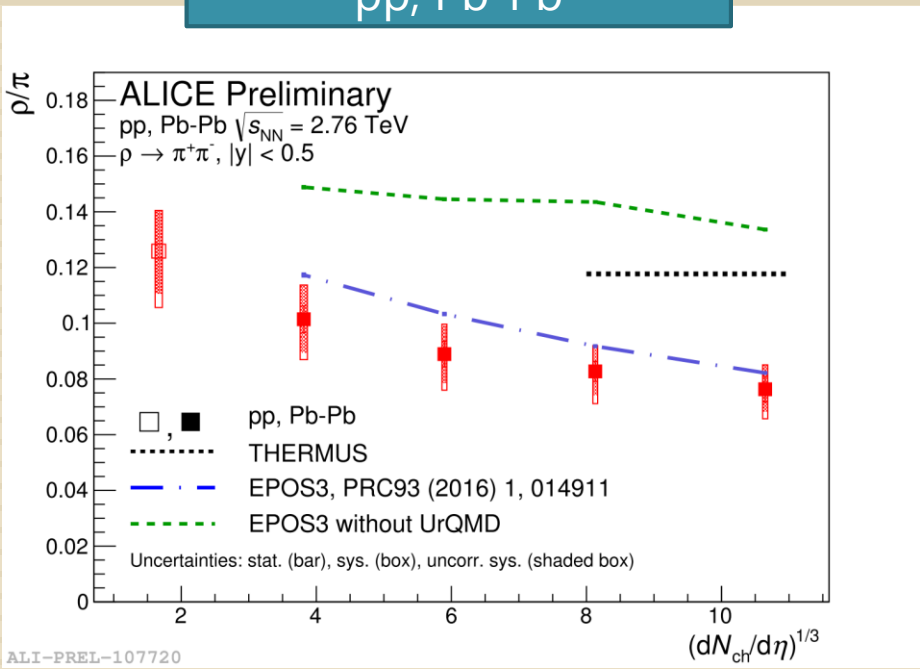
Light-flavor resonances

pp, Pb-Pb



PRC 91 (2015) 024609

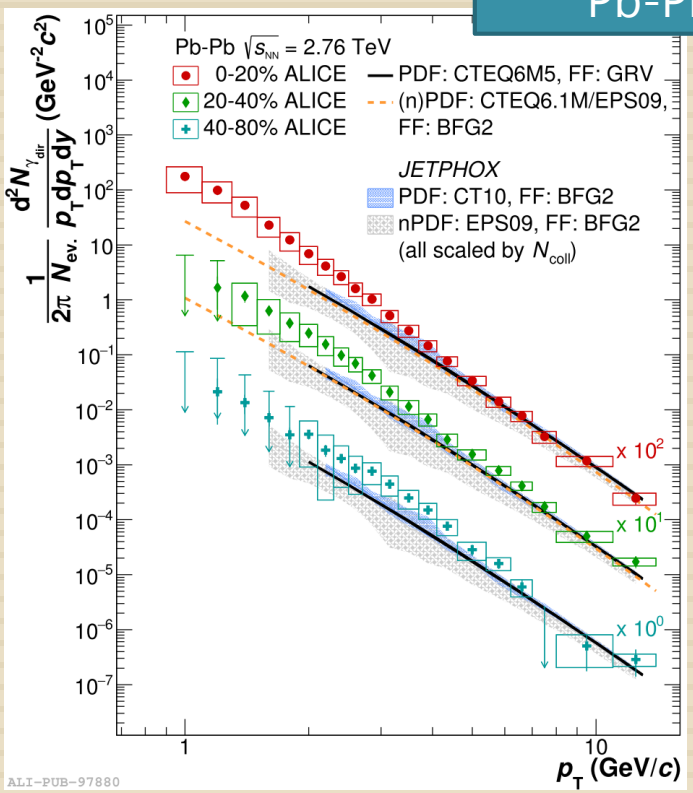
pp, Pb-Pb

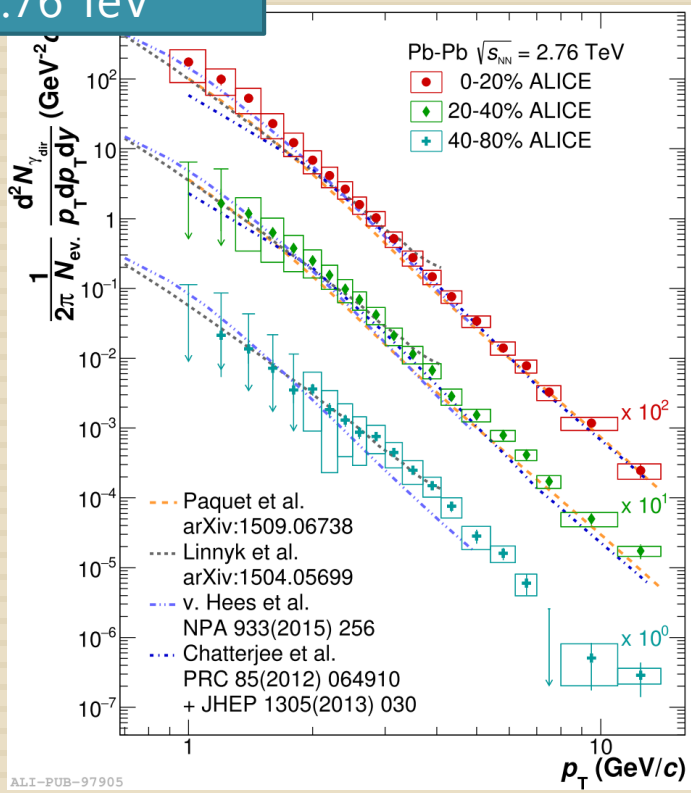


- ϕ/K stays almost constant
  - Long lifetime (46 fm), small hadronic interaction cross section
- K*/K, ρ/π decreases with increasing multiplicity
  - Rescattering > Regeneration
  - EPOS3 with UrQMD afterburner qualitatively describe the decreasing trend

Thermal photon

Pb-Pb 2.76 TeV





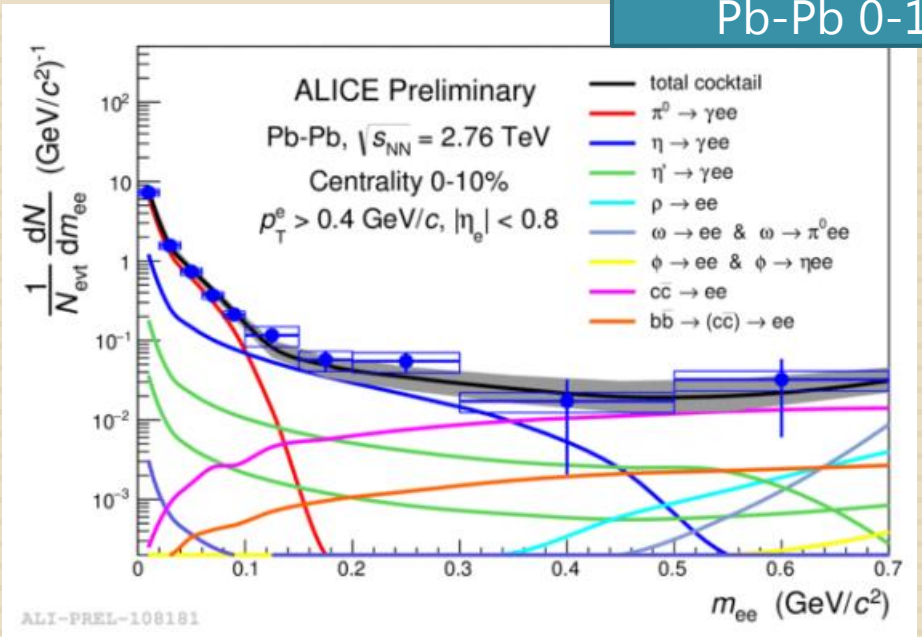
PLB 754 (2016) 235

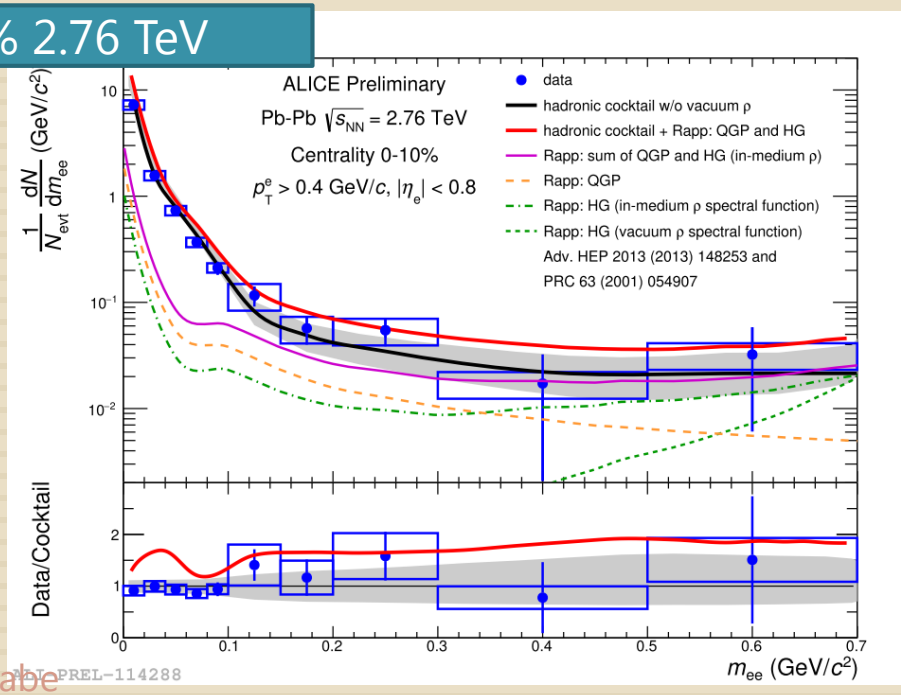
- 2.6σ excess from pQCD caluclations in 0-20% central
  - Thermal contribution: T_{eff} = 297 ± 12 ± 41 MeV (30% higher than RHIC)
- Data points are consistent with model calculations within uncertainties

Low mass dielectron

- Dielectron spectra in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
- Consistent with no enhancement
  - Large experimental uncertainties and large charm cross sections at LHC energies
  - Extracted limits compatible with ALICE real photon measurements
  - Consistent with a model that successfully describes SPS, RHIC data.

Pb-Pb 0-10% 2.76 TeV





Summary

- ALICE is an ideal place to study the properties of QGP
  - Flow: hydrodynamical models with small η/s qualitatively describe the data
  - Jet suppression: strong suppression of high-p_T particles and modifications in jet shapes are observed
  - Heavy flavor: strong suppression and positive v_2 are observed
  - Quarkonia: J/ψ results support a picture of J/ψ suppression and regeneration in the medium
  - LF resonances: interactions in hadronic phase play a significant role to understand the final yield
  - Photon: excess from pQCD calculation at low p_T
  - Low mass dielectron: consistent with a model describing SPS and RHIC results
- Much more results to come in near future (QM2017)